TCE (Trichloroethylene) transport and degradation in fractured rocks

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I. Abstract

Water samples collected in the mudstone aquifer underlying the Naval Air Warfare Center, West Trenton, NJ (2008-2013) (Imbrigiotta et al., 2017) were analyzed in this paper to understand the transport and degradation process of trichloroethene (TCE). Révész et al. (2014) conducted their bioaugmentation (BA) experiment on this site during the data collecting period. The purpose of their BA experiment was to introduce and stimulate microbial species capable of degrading TCE (Imbrigiotta et al., 2017). After the injection of electron donors and microbes, the quick concentration change of TCE and cis-dichloroethene (cis-DCE) and a much slower change of vinyl chloride (VC) and ethene indicated that microbes prefer to and are more active to degrade organic contaminants with more chlorine present. TCE concentration change along the flow path indicated that most biotic degradation happened in situ. The analysis demonstrates that microbes with electron donors can quickly reduce concentration of TCE, but it takes more than 5 years, maybe decades, to finally degrade TCE to ethane. The degradation process slowed down after a year, this might be due to lacking electron donors in the water and/or unhealthy microbe communities.

II. Introduction

Trichloroethene (TCE) is a ubiquitous groundwater organic contaminant (U.S. Department of Health Human Services, 2005a) and a suspected human carcinogen (U.S. Department of Health Human Services, 2005b). The U.S. EPA drinking water standard for TCE has been set at 5 parts per billion (ppb) (EPA 540/R-94/044). TCE is an effective solvent for many organic materials. It was used as a metal degreaser

and to clean kerosene-fueled rocket engines. TCE usually does not affect surface water ecosystem because microbes are much more abundant and active in surface water than in groundwater (McKnight et al., 2010). TCE occurs as dense non-aqueous phase liquid (DNAPL), which usually transports to the confined layer at the bottom of an aquifer.

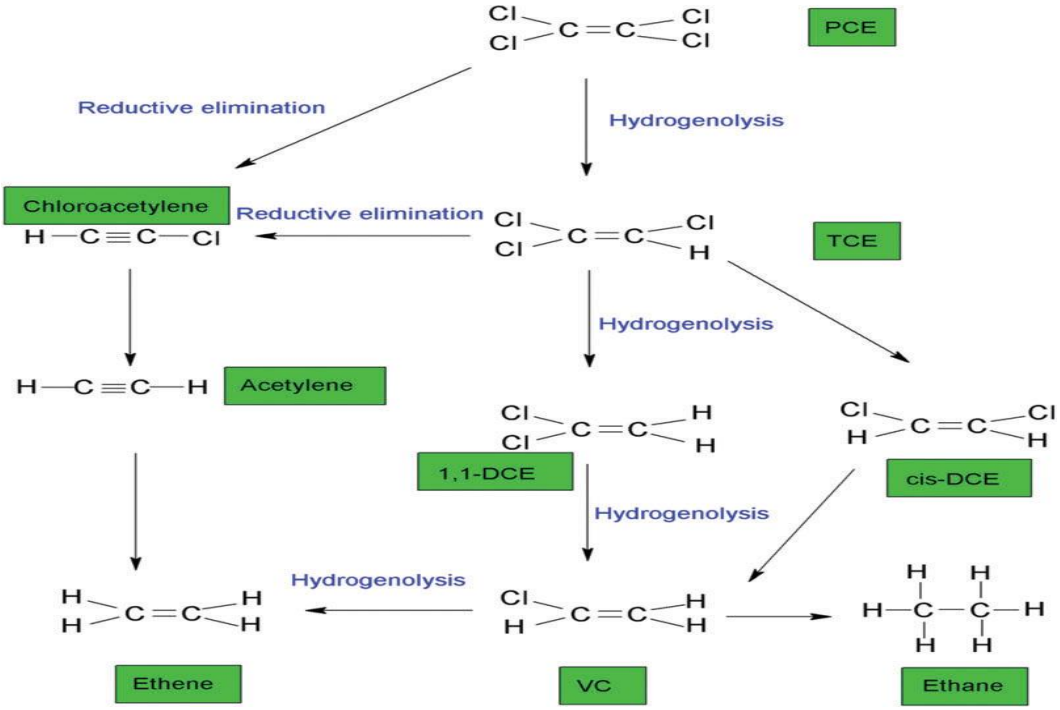

Fig. 1. Summary of chlorinated ethene degradation pathways and products (He et al., 2015)

TCE in watersheds can go through abiotic and biotic degradation. Some of the degradation reactions on the right may occur through both biotic and abiotic pathways (Lojkasek-Lima, Paulo, et al.). A common pathway that is talked about in this paper is TCE – cis-DCE – Vinyl chloride – Ethene.

Reductive dechlorination is thought to be responsible for the natural attenuation of chlorinated solvents at sites with suitable environmental conditions (U.S. EPA, 2008; Wiedemeier et al., 1999). Ferrous minerals especially FeS and FeS_2 are effective in degrading chlorinated contaminants such as TCE (He et al., 2015).

Site Background

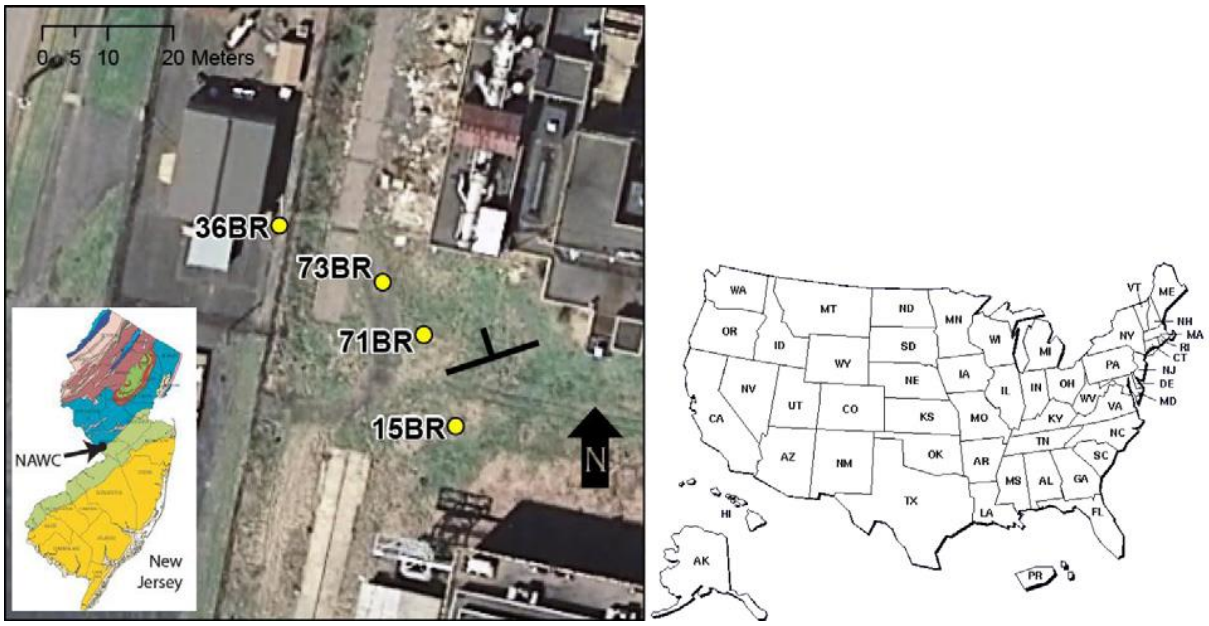

Fig. 2. The location of the In Situ Test Facility (ISTF) at the Naval Air Warfare Center (NAWC) in West Trenton, NJ. The ISTF has been used for detailed investigations of the fate of chloroethenes in fractured rock. The long axis of the black T symbol is the direction of the strike of the dipping beds (geologic strata), and the short axis points in the downdip direction. (Revesz et al., 2014)

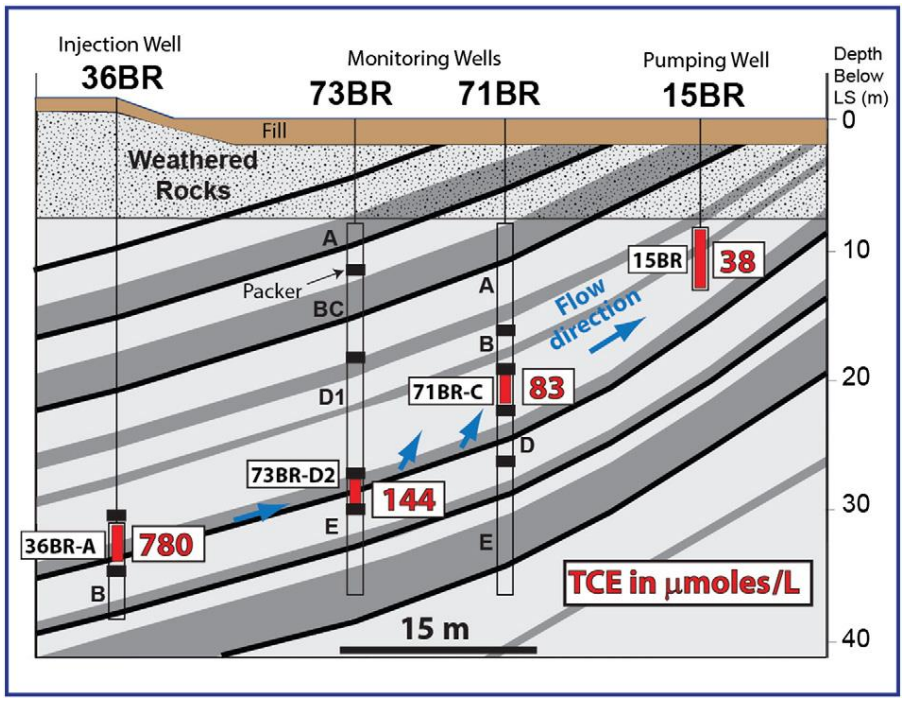

Fig. 3. Geologic cross section through the In Situ Test Facility, showing the dipping mudstone beds. Light gray beds are massive mudstones; dark gray beds are laminated mudstones, and thin black beds are carbon-rich mudstones. Red packed-off intervals (73BR-D2 and 71BR-C) are along the primary transport path between 36BR-A and 15BR. Other packed-off intervals have labels that omit the well name. TCE concentrations are mean values based on measurements during the six months preceding injection of the bioaugmentation amendments (March through October 2008). (Revesz et al., 2014)

The data that this paper analyzed was from Imbrigiotta et al. (2017) and was collected at the former Naval Air Warfare Center (NAWC) site in West Trenton, New Jersey (Fig. 2). TCE was used as a refrigerant for about 40 years at the site and resulted in two sources areas of contamination (Goode et al., 2007; Lacombe, 2000). 36BR is the injection well of electron donors and microbes which facilitate biotic TCE degradation process in the bioaugmentation experiment by Revesz et al.

III. Methods

The purpose of this study is to understand the transport and degradation process of TCE.TCE, cis-DCE, VC and Ethene concentration was monitored before and after an injection of electron donors to well 36BR. Data was collected in well 36BR, 71BR, 73BR and 15BR, which were the flow path of TCE determined by Revesz et al. (2014). Based on the geologic cross section (Fig. 2), monitoring wells 71BR and 73BR were further divided into 5 subsections. Data of concentrations of TCE and its daughter products were collected for all subsections.

This study focused on biotic degradation even though both abiotic and biotic degradation existed at the site. The injection of electron donors helped microbial communities facilitate degradation of Chlorinated Ethenes (CE), so the concentration change after the injection only related with biotic degradation.

IV. Results and discussion

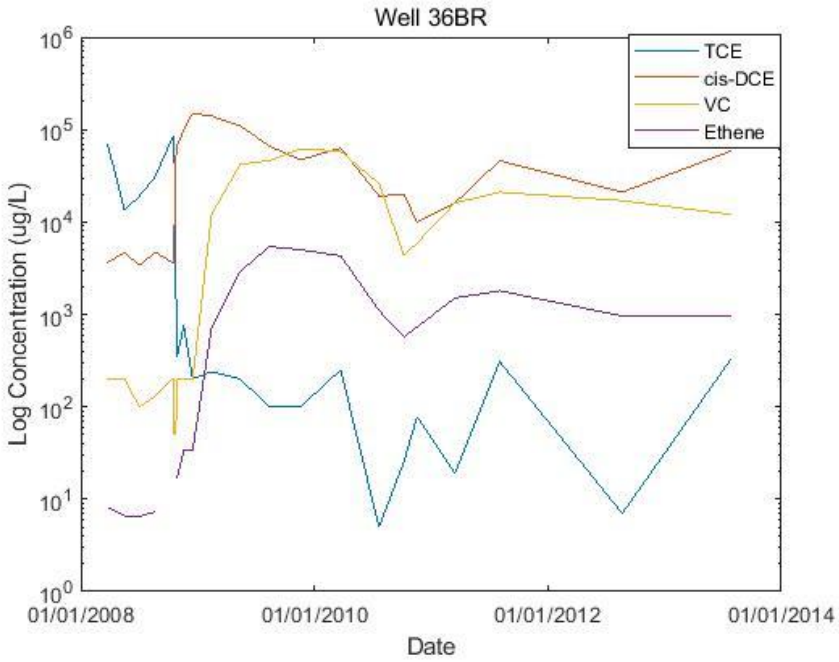

Fig. 4: Concentration of TCE, cis-DCE, VC and Ethene in well 36BR during the sampling period. Y axis is in log scale. Concentration is in microgram/liter

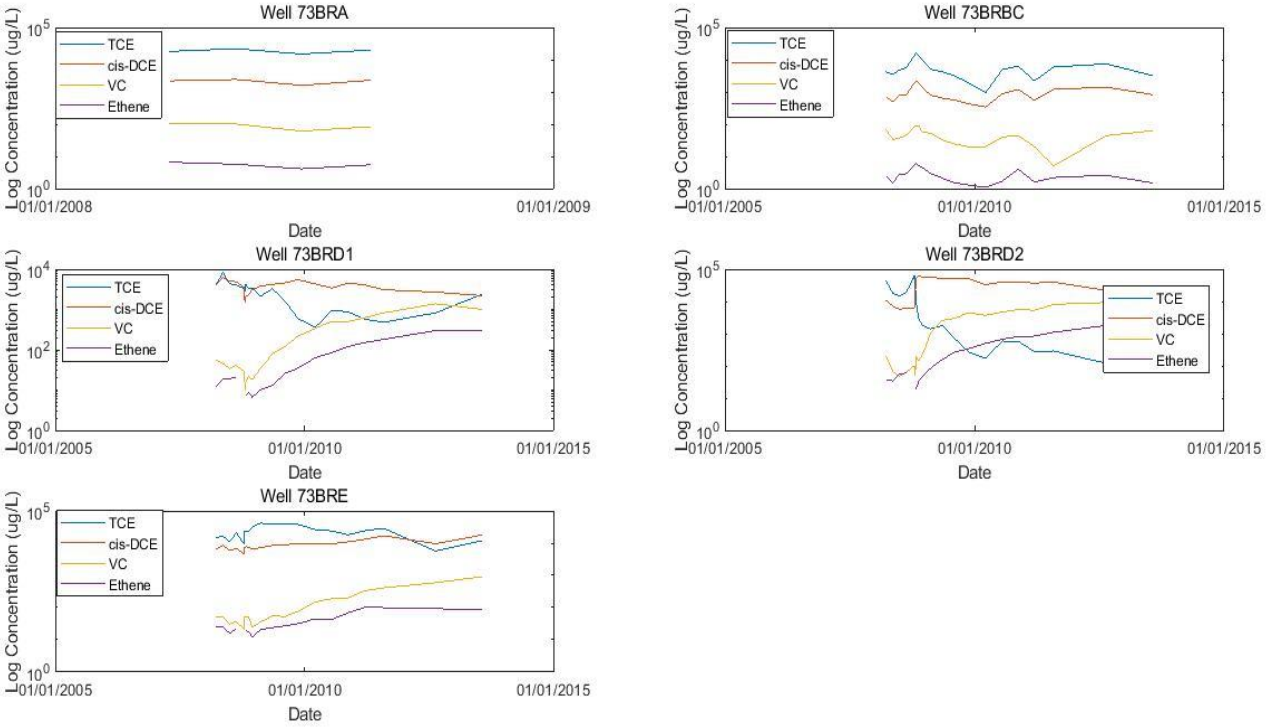

Fig. 5: Concentration of TCE, cis-DCE, VC and Ethene in well 73BR during the sampling period. Y axis is in log scale. Concentration is in microgram/liter.

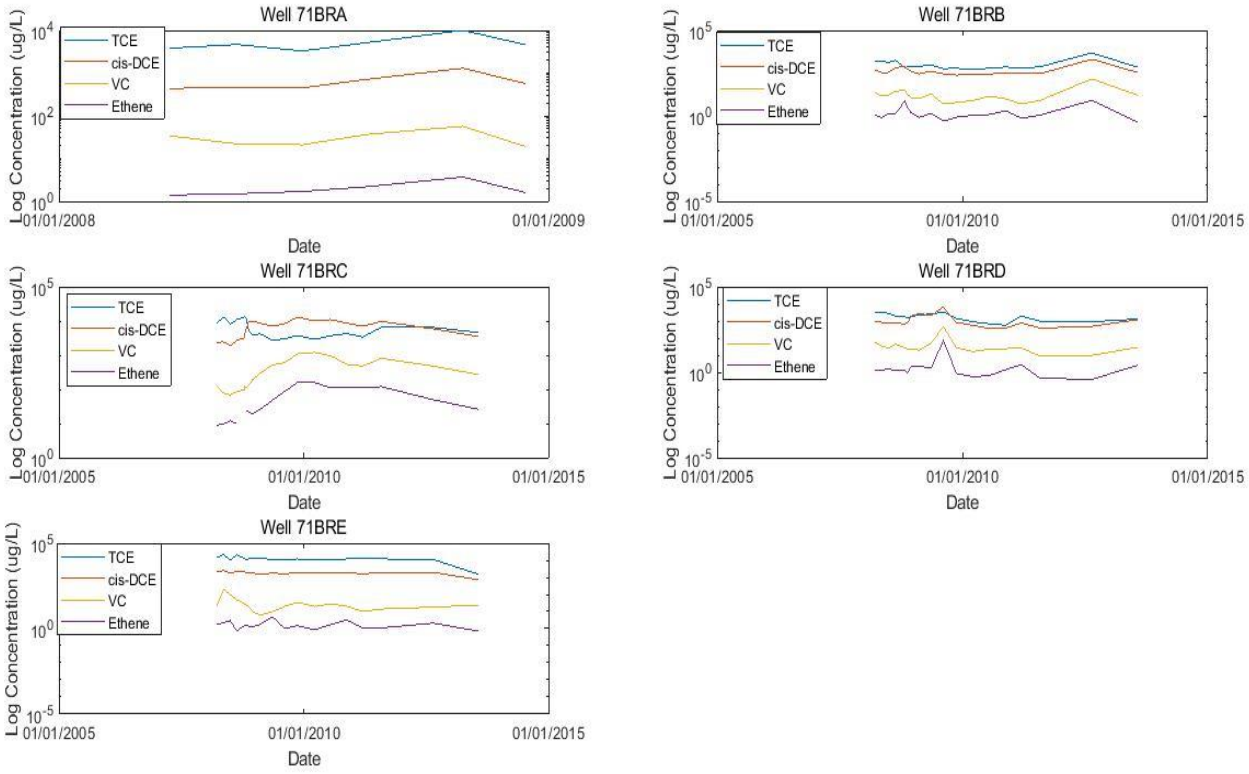

Fig. 6: Concentration of TCE, cis-DCE, VC and Ethene in well 71BR during the sampling period. Y axis is in log scale. Concentration is in microgram/liter. A, B, C, D, E refers to different depth of Well 71BR. A is the shallowest section and E is the deepest section.

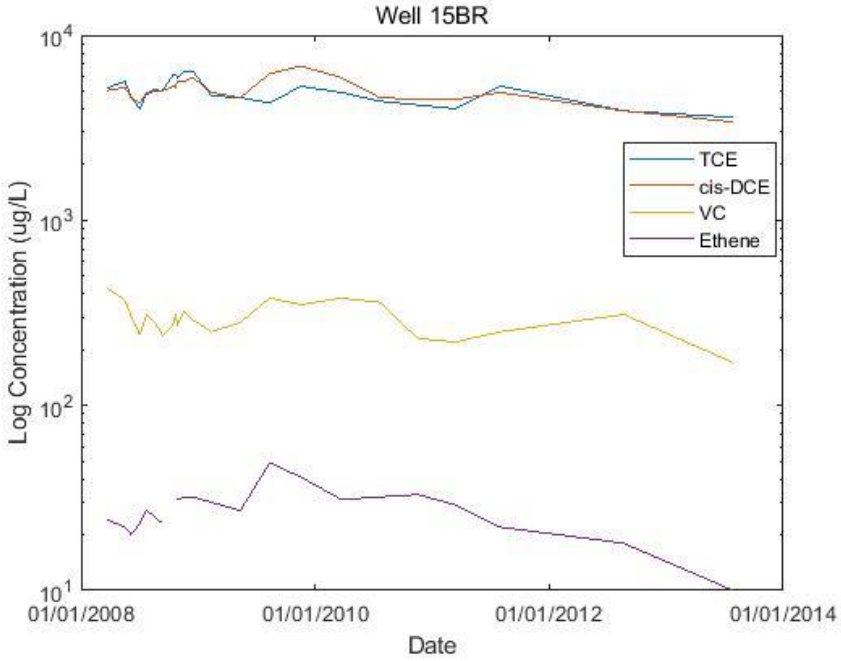

Fig. 7: Concentration of TCE, cis-DCE, VC and Ethene in well 15BR during the sampling period. Y axis is in log scale. Concentration is in microgram/liter.

An abrupt decrease in TCE and increase in cis-DCE concentration in well 36BR (Fig.4) occurred in late October 2008, right after the injection of electron donor and microbes. VC and ethane concentration started to quickly increase after two to three months of the injection. More than 90% of TCE were degraded due to the injection. The degradation speed decreased after a year. TCE concentration fluctuated at the end of the sampling period.

Similar with the pattern in well 36BR, TCE concentration in well 73BRD2 decreased right after the injection and cis-DCE concentration increased simultaneously (Fig.5). In all packed-off intervals, 73BRD1 showed a similar pattern with well 73BRD2 which is along the primary transport path between 36BR and 15BR. CEs concentration in Well 73BRA was the least affected among all intervals. This finding indicated that the microbes could only reduce TCE concentration in the rock matrix around the well due to processes such as diffusion and desorption.

TCE and cis-DCE concentration in well 71BRC (Fig.6) shows a similar decreasing and increasing pattern as 73BRD2 respectively. TCE concentration did not drop as quickly and much as it did in well 36BR and 73BRD2, indicating that either the microbial activity or the concentration of electron donors decreases with respect to increasing transport distance. CE concentration in Well 71BRA was the least affected by the injection among all intervals.

Comparing with CE concentrations in other wells along the flow path, those in 15BR (Fig.7) were the least affected by the injection of electron donors in well 36BR. TCE and cis-DCE concentration changed slowly over time.

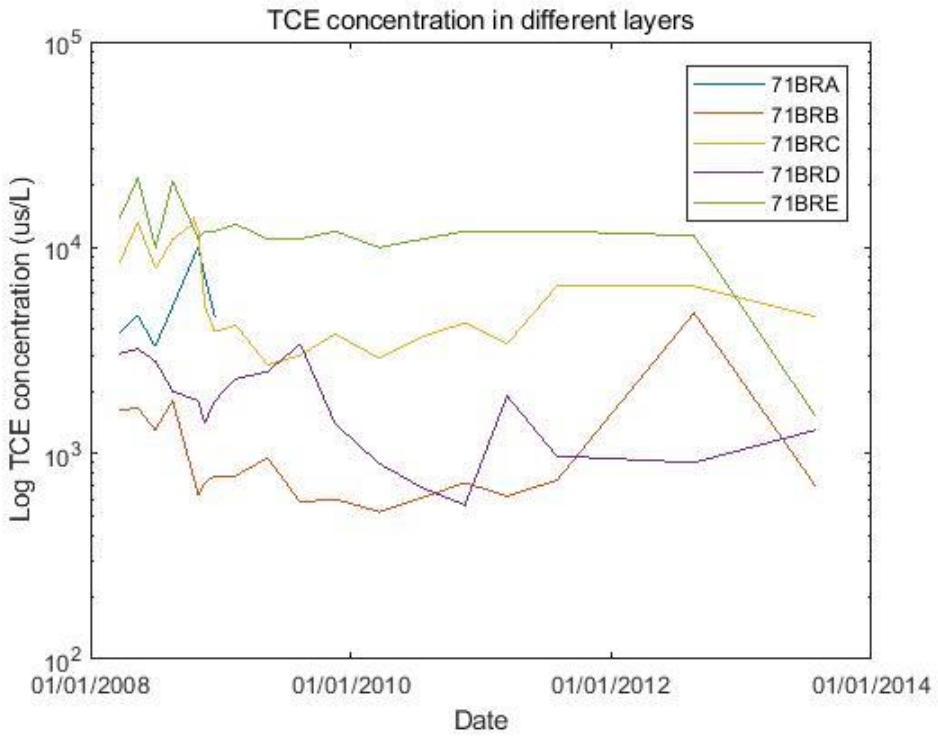

Fig. 8: TCE concentration in well 71BR. Note that Well 71BRA has a much shorter sampling period than the others.

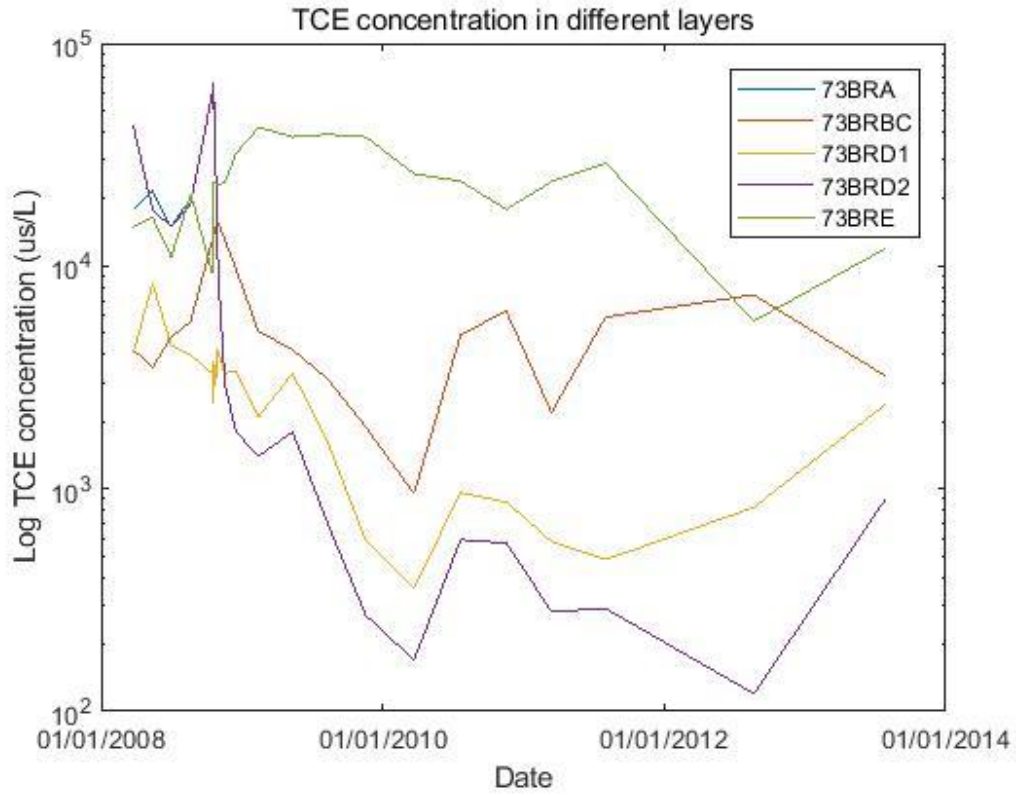

Fig. 9: TCE concentration in well 73BR. Note that Well 73BRA has a much shorter sampling period than the others.

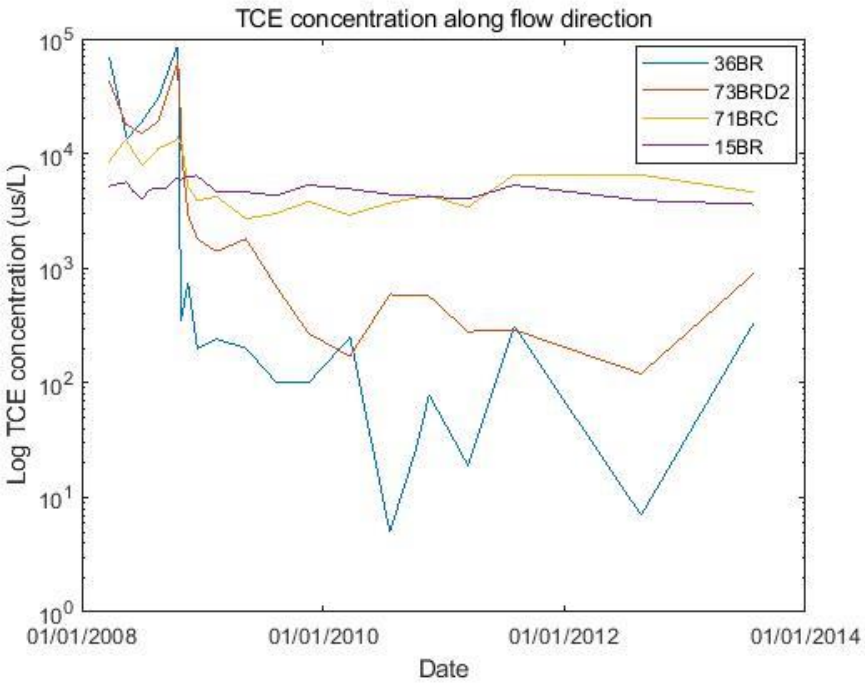

Fig. 10: TCE concentration along flow direction. Flow direction was determined by Revesz et al., 2014, from Well 36BR, to Well 73BRD2, to Well 71BRC, to Well 15BR.

TCE concentration in 71BRC and 73BRD2 decreased at the highest rates among most packed-off intervals of well 71BR and 73BR in Figure 8 and 9, demonstrating that 71BRC and 73BRD2 are along the major flow path. The finding also indicates that microbes mostly degrade CEs in situ. Microbes had less effect to CE concentration in another layer. TCE concentration from 71BRA could be an outlier due to spill of TCE directly on the ground. Figure 10 shows that the degradation rate decreased with respect to increasing transport distance, which also indicated that biotic degradation is mostly in situ.

V. Conclusions

Water samples collected in the mudstone aquifer underlying the Naval Air Warfare Center, West Trenton, NJ (2008-2013) (Imbrigiotta et al., 2017) were analyzed to understand the transport and degradation process of TCE. In this paper,

we discuss microbes' favor to degrade high-order CEs such as TCE. When transport distance increases, the rate of CE degradation decreases, indicating that biotic degradation is mostly in situ. Future study can focus on the fluctuation at the end of the sampling period. One hypothesis is that it is due to back diffusion, but more data need to be analyzed to confirm or decline it. Also, because TCE degrades to VC, which is more toxic than TCE and harder to degrade by microbes, monitoring VC concentration to determine whether the dechlorination has progressed past the dehalogenation of VC is necessary after treatments of TCE (Révész et al. 2014).

VI. References

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